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Effect of Crop Rotation and Manure on the Yield and Quality of Sugar Beets, United States Scotts Bluff (Nebr.) Field Station, 1930-41

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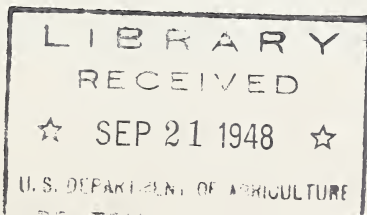
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ACRE yields of sugar beets on farms are reported as tons of roots harvested. The percentage of sugar in the roots is a very significant factor in determining their value for processing. Therefore, the acre yield of sugar as obtained by multiplying root yields by the sugar content (sucrose percentage), expressed as a percentage, represents the best measure of crop value. The full value of the crop, however, must include also the returns from valuable byproducts—crowns, leaves, molasses, and beet pulp—that are used for cattle feed. In general, these products are in proportion to the acre yields of sugar.

Sugar beets are frequently purchased on a sliding price scale per ton, based on the percentage of sugar in the roots. Obviously, high tonnages without sacrifice of sugar content are desirable. Farm practices conducive to maximum yields frequently are not favorable to the maintenance of high percentages of sugar. The common experience is that as one factor rises or falls the other factor moves in the

¹ In cooperation with the Nebraska Agricultural Experiment Station. Report on these rotations for the period 1930-35 was made in U. S. Dept. Agr. Cir. 444. 1937.



opposite direction. The problem to be faced by grower and factory is how to produce high root yields without so reducing the quality as to offset the effects of the increased yields.

The proper arrangement of crops in the rotation and proper application of farm manures exert a definite influence upon both the yield and quality of sugar beets. This circular presents the results of investigations covering periods of either 10 or 12 years on 24 different crop rotations that included beets. The data have been studied to determine the influence of rotations and manure applications upon the yield and quality of the beets. A report (4)² was made on these rotations when data for 6 years were available. Opportunity has therefore been afforded to check the preliminary conclusions of the earlier study.

ROTATIONS

DESCRIPTION

The data on rotations were obtained from the crop rotations maintained at the Scotts Bluff Field Station (table 1). This station was established in 1910, 6 miles east of Mitchell, Nebr., and 5 miles north and 2 miles west of Scottsbluff. The land is irrigated by water supplied by ditches of the North Platte reclamation project. Thirteen of the rotations were begun in 1912, and others were added in 1920 and 1926. The land was first brought into cultivation only a few years before 1910. The 1920 and 1926 rotations were begun on land that had been in other crops from 1910 to the establishment of the rotation plots. The details of the methods of handling the plots and growing the crops, together with the arrangement of plots, and the results obtained from the rotations have been given in former publications (2, 3, 4, 6). Scofield and Holden (6) and Hastings (1) have given detailed descriptions of the rotation field. The size of the plot for each crop in any rotation was 132 by 82½ feet. In all rotations, a crop representing each step in the rotation was grown every year; that is, a 6-year rotation had 6 plots.

Hastings (2) states that the soil where these investigations were conducted is Tripp very fine sandy loam, that it is typical of the extensive areas lying north of the North Platte River, and that soils of this type are among the more productive on the project. On the basis of the soil survey of Scotts Bluff County (7), Hastings (2) notes that the chief soils of the project range from a sandy loam to a loamy fine sand, with Mitchell very fine sandy loam predominating. The location of this station is such that there have been no seepage or drainage problems on the rotation plots. There is no water table within 40 feet of the surface.

The crops grown in these rotations and their order of arrangement within rotations were similar to many in general use on irrigated lands throughout the North Platte Valley. Some of these rotations were desirable and produced good yields of sugar beets and other crops. Others proved undesirable in that soil fertility was not maintained and unprofitable yields were obtained for sugar beets (4) and for other crops (1, 2, 3, 6).

² Italic numbers in parentheses refer to Literature Cited, p. 20.

TABLE 1.—*Crop rotations in which sugar beets were grown, Scotts Bluff Field Station, Mitchell, Nebr.*

FIELD K			
Rotation, type, and number	Year started	Years in rotation	Cropping system
Continuous cropping with sugar beets:			
2	1912	<i>Number</i>	Sugar beets, continuous.
Short rotations without soil-building legume crops:			
20	1912	2	{ Sugar beets; potatoes.
21			{ Sugar beets; potatoes (manured).
22			{ Sugar beets; oats.
23		3	{ Sugar beets (manured); oats.
30			{ Sugar beets; potatoes; oats.
31			{ Sugar beets (manured); potatoes; oats.
32			{ Sugar beets; corn; oats.
4-year rotations with soil-building legume crops:			
40	1912	4	{ Sugar beets; alfalfa (2 years); potatoes.
42			{ Sugar beets; alfalfa (2 years); oats.
45-1	1920		{ Sugar beets (2 years); oats and sweetclover; sweetclover (pastured with sheep); first crop of sugar beets.
45-2			{ Second crop of sugar beets in the above rotation.
Longer rotations with soil-building legume crops:			
60	1912	6	{ Sugar beets; alfalfa (3 years); potatoes; oats.
61			{ Sugar beets (manured); alfalfa (3 years); potatoes; oats.
62			{ Sugar beets; alfalfa (3 years); corn; oats.
64	1920	7	{ Sugar beets; oats; alfalfa (3 years); potatoes.
71-1			{ Sugar beets; sugar beets (manured); oats; alfalfa (3 years); potatoes. First crop of sugar beets.
71-2			{ Second crop of sugar beets (manured).

FIELD E

Short rotations with soil-building legume crop (sweetclover):			
13	1926	2	Oats with sweetclover (green manure, fall-plowed); sugar beets.
15			Same as 13, except that sweetclover was pastured with sheep before fall plowing; sugar beets second year.
19		3	Same as 13, except that hay was removed in fall before plowing; sugar beets second year.
33			Sugar beets; oats and sweetclover (spring-plowed, green-manured); potatoes.
4-year rotations without soil-building legume crop:			
46-P	1926	4	Potatoes, sugar beets, oats, sugar beets. First crop of sugar beets.
46-O			Second crop of sugar beets in the above rotation.
4-year rotations with soil-building legume crop:			
43	1926	4	Oats seeded with sweetclover (pastured with sheep fall and spring); potatoes; oats and sweetclover (pastured with sheep, fall-plowed); sugar beets.
47			Oats seeded with sweetclover (spring-plowed June 1); potatoes; oats seeded with sweetclover (fall-plowed); sugar beets.
41			Sugar beets; oats and sweetclover (fall-pastured with sheep); sweetclover (pastured with sheep and fall-plowed); potatoes.

In these rotations, no commercial fertilizers were used, although the outline was revised in 1942 and since then commercial fertilizers have been added to some of the rotations. Applications of barnyard manure where use was indicated was limited to 12 tons per acre. Not more than one application was made during the period of any rotation. One 2-year rotation received manure at the rate of 12 tons per acre each alternate year, an average of 6 tons per year. In the 6-year rotations,

when manure was applied it was spread on one of the six plots each year, which was an average for the rotation period of only 2 tons per year. In some other work at this same station (3, 4, 5), farm manures were applied to sugar beets at much heavier rates. In these studies on the use of farm manures for sugar beets, it is found that the application of more than 12 tons per acre per year is not profitable.

STANDS

In each year of test the rotations had initial and thinned stands of sugar beets adequate to warrant inclusion of the data. Some replanting was necessary because of soil crusts or weather injury on certain plots. The stands as reported for these rotations were determined by making counts of the number of living beets in several parts of each plot during the latter part of September, or a short time before harvest. With 100 plants for 100 feet of row taken as a full stand, these counts when averaged and reduced to 100-foot basis represented, for a rotation, the full-stand percentage. The average stand in field K for a period of 12 years was 73 percent, and for field E for a 10-year period, 65 percent.

High-yielding plots are those upon which the best stands are obtained. This does not necessarily mean that 100-percent stands produce high yields, but it does indicate that soils capable of producing high yields usually are those upon which the better stands are obtained. Plot 2 (continuous sugar beets) has not shown a very high average stand, but observations year after year have revealed that at thinning time stands are much better than at harvest. As with plot 2, some of the other low-yielding plots have shown much greater mortality of plants from thinning time to harvest than occurs on the more fertile plots. In rotations in which sugar beets immediately followed sweetclover, some of the variations in stand were due to loss of plants in eradicating sweetclover, which persisted in the plots as a weed.

INJURY FROM NEMATODES, INSECTS, AND PLANT DISEASES

The sugar-beet nematode did not appear in any of these plots, even the one with 30 years of repeated cropping. The shorter intervals between beet crops in some of the rotations are favorable to its introduction if precautions are not taken to avoid bringing dump dirt to the fields. This nematode is prevalent on some nearby farms. Root knot nematode has done some damage for several years to the beets on several of the rotations. Insect injury was not severe on any of the plots, although poisoning for cutworms and grasshoppers was occasionally necessary. The common sugar-beet diseases, such as root rot, leaf spot, and the damping-off diseases of young plants, were often present in varying intensity.

MATERIAL AND METHODS

The methods employed in the production of the various crops have conformed to the general cultural practices used in the area. The beets are planted about April 20 with 20 pounds of seed per acre in rows 20 inches apart. Thinning to 12 inches apart in the row is done

by hand. The crop is harvested late in October, and all beets are weighed to determine the root yields.

To determine the sucrose percentages and apparent-purity coefficients, the plots were sampled by taking from each plot at random 100 normally competitive beets; that is, those having neighbors on four sides at approximately the proper distances. In the first 2 years these were divided into 10 samples of 10 each, but during the last 8 years they were grouped into 5 samples of 20 each. Sucrose was determined by the Sachs-Le Docte method.

Apparent-purity coefficients were computed from refractometer readings of total solids in the period 1932-38, replacing the Brix spindle method used in 1930 and 1931. Apparent purity is positively correlated with sucrose percentage. Indicated available sugar (root weight $\times$ sucrose $\times$ apparent-purity coefficient, used as a percentage) is a useful index of proportionate value of crops from the standpoint of manufacture of sugar. Study of the detailed data from the rotations shows that, within the ranges of sucrose percentages and apparent-purity coefficients obtained, the yields of indicated available sugar in the rotations follow the same general course as the yields of gross sugar. For this reason apparent-purity determinations were discontinued in 1939, and these data for the 9-year period were not reported.

Eight of the rotations in field E were discontinued in 1939, and results from this field were given as averages for the 10-year period 1930-39. The 16 rotations in field K were continued and were reported for the 12-year period 1930-41. The rotations are grouped in tables 1 and 2 to facilitate comparisons of the effects of certain types of rotations upon the yield of sugar beets and other crops. The data from rotations that did not receive manure are given along with data from comparable rotations in which manure was applied.

The analysis of variance method of statistical analysis was used with the detailed data for sugar beets from the 24 rotations and the one continuously cropped plot. The years were the replication factor, the various crop rotations the treatment factor, and residual variance data were used to compute the experimental error. Significance was judged from the customary 5-percent point.

The design of the rotational tests employed has limited the statistical evaluation that can be applied. Variance assignable to "years" can be determined, but there are confounded in this variance the effects attributable to differences in plot productivity, since the data for a crop in any one year are obtained from single plot sites within the series on which the given rotations are employed. More precise statistical evaluation would require a number of replicated plots in each year for each rotation. Despite the lack of replication, confidence can be placed in some of the differences among rotations, because these differences are so large and so consistent for certain treatments regardless of plot location.

In field K there were 15 rotations, consisting of one 7-year, four 6-year, three 4-year, three 3-year, and four 2-year rotations from which sugar-beet yields were obtained for many years. Some measure of the adequacy of the time period for judgment on the results can be obtained if intercomparisons among these data are made. If, for example, all plots grown in even-numbered years of the 12-year period

are compared with those of odd-numbered years, the averages from companion parcels of land can be contrasted. Such comparisons were made, and the mean differences in yield, with one exception, were not significant.

Sugar-beet yields for a 30-year period are available from records at the Scotts Bluff Field Station for certain rotations. Odd- and even-year comparisons for the 30-year period with the 2- and 3-year rotation series, respectively, showed no significant yield differences among companion parcels. Similarly, intercomparisons in the 4- and 6-year rotations showed that rotations 40 and 42 were located on plots of greater variability than average, but differences were not significant. In the 6-year rotations over the 30-year period, significant differences among parcels existed. Since the data here presented cover 12 years, or two full cycles of the 6-year rotations, however, inequalities from differences in soil fertility should be balanced.

The correlation coefficient between root yields and sucrose percentages was determined as -0.61 , significant above the 1-percent point. This expected relationship, however, should not preclude consideration of the relative effects of a practice, since from the practical standpoint increases in tonnage not balanced by commensurate decreases in sucrose are highly desirable, as also are increases in sucrose not accompanied by equal or greater losses of tonnages. So long as sucrose percentages are fairly high, direct comparisons of gross sugar production immediately show the valuable treatments and those that are unprofitable.

RESULTS FROM VARIOUS ROTATIONS

The data in table 2 were given as either 10- or 12-year averages obtained from the individual plots of the 24 rotations included in this study.³ The results obtained permit a number of comparisons of the effect of various crops upon sugar-beet yield and quality. The value of such legume crops as sweetclover and alfalfa in the rotation can be estimated. In some of the rotations, methods of handling the land in order to change from legume crops to sugar beets have been contrasted. Various other factors directly applicable to sugar-beet production, and especially the value of application of farm manures, can be appraised. These are discussed under appropriate headings, such rotations as afford pertinent information being contrasted.

LENGTH OF ROTATIONS

The series of rotations do not permit adequate comparison of the long rotations contrasted with the short ones in their effects on the production of sugar beets. When there is a short interval between sugar-beet crops, the intervening crop is a nonlegume; when the

³ Detailed annual records of sugar beets and other crops grown in fields K and E, respectively, are not included in this circular. Copies in mimeographed form are available. Those interested in the complete record may obtain these data from the Scotts Bluff Field Station, Mitchell, Nebr., or from the Division of Sugar Plant Investigations, Plant Industry Station, Beltsville, Md.

interval is long, then a legume crop is included. This factor needs to be taken into consideration if crop differences are to be attributed to rotation length, disregarding the crops employed. The differences in yield of sugar beets in the short rotations, as compared with those in the long, probably should be interpreted as indicative of the effect of the legume crop rather than of rotation length. The longest rotation used in these tests was 7 years, and that is not exceptionally long for this general area. Sugar-beet growers, as a rule, do not practice continuous cropping or short rotations without applying manure. In the rotations at the field station the alfalfa is left for only 2 and 3 years, and many growers permit the alfalfa crop to grow for more than 3 years.

CONTINUOUS CROPPING WITH SUGAR BEETS

Plot 2, on which sugar beets have been grown continuously for 30 years without any application of manure, is not a plot planned for presentation of a proper practice but has been maintained for purposes of comparison to indicate the ill effects of intensified cropping. It has been a good source of information regarding the extent to which soil fertility may decline and regarding the increase in prevalence of sugar-beet diseases that may take place under such conditions.

The mean yield of beets from this plot during the past 12 years was 5.65 tons of roots per acre; the average sucrose percentage of the roots, 18.13 percent; and the average acre yield of gross sugar, 2,044 pounds (table 2).

In tons of roots and sugar production, the yields from plot 2 were lower than those of any rotation-plot series. Rotation 22, in which sugar beets alternated with oats, had a 12-year mean sugar-beet production of 7.82 tons of roots and 2,737 pounds of gross sugar per acre and was next to plot 2 with respect to low root yield. The requirements for significant differences in yield in field K are 1.48 tons of roots and 520 pounds of gross sugar per acre, and both requirements were exceeded by the gains in yield that the beet crop from rotation 22 shows over plot 2.

The sucrose percentage and the apparent-purity coefficient are higher from plot 2 than from any rotation in field K. The sucrose percentages, however, are not significantly better than those from several of the other rotations. The difference required for significance is 0.82 percent. Five of the rotations in field K produced beets with a mean sucrose content above 17.50 percent. The fact that plot 2 sugar beets are significantly lower than those from all rotations both in yield and gross sugar per acre, although they exceed significantly many rotations in sucrose percentage, provides an excellent illustration of the necessity for the grower to consider the yields as well as the sucrose percentage of his crop. The indications are that yield may be materially reduced with an insufficient recompense by gains in sucrose percentage. A contrast of continuous cropping and a 2-year intensive rotation without manure are shown in figure 1.

TABLE 2.—*Comparative acre yields of sugar beets and other crops in rotations at the Scotts Bluff Field Station, Mitchell, Nebr., and sucrose content of sugar beets*

Data given as averages for the 12-year period 1930-41 for field K and for the 10-year period 1930-39 for field E]

FIELD K

Rotation type and No.	Length of rotation	Sugar beets			Alfalfa			Sweetclover	Potatoes		Oats	Corn
		Roots	Gross sugar ¹	Sucrose	1st year ²	2d year	3d year					
Continuous cropping with sugar beets:	Years	Tons	Pounds	Per-cent	Tons	Tons	Tons		Push-els	Push-els	Bush-els	
2		5.65	2,044	18.13								
Short rotations without soil-building legume crops:												
20	2	7.82	2,767	17.60					127.5			
21 (potatoes manured)		16.77	5,717	17.05					237.5			
22		7.82	2,737	17.56						30.1		
23 (sugar beets manured)	3	17.74	5,873	16.65						55.3		
30		7.84	2,813	17.95					155.9	34.2		
31 (sugar beets manured)		16.65	5,959	17.97					233.5	55.9		
32		7.67	2,754	17.94						29.4	30.5	
4-year rotations with soil-building legume crops:												
45-1	4	15.58	5,306	16.39				Pastured ³				
45-2		13.58	4,872	17.59				(³)		41.7		
40		15.02	4,897	16.27	0.577	4.723			283.5			
42		13.27	4,429	16.77	.503	4.037				55.0		
Longer rotations with soil-building legume crops:												
60	6	13.45	4,271	15.86	.654	4.079	4.735		274.9	57.5		
61 (sugar beets manured)		17.34	5,474	15.78	.684	4.777	5.511		300.2	62.0		
62		13.98	4,585	16.41	.634	4.065	5.020			56.4	49.8	
64		15.89	4,925	15.47	3.568	4.995	5.163		320.7	48.8		
71-1	7	13.57	4,128	15.17								
71-2 (sugar beets manured)		16.58	5,256	15.98	3.455	4.087	4.780		289.7	57.0		

FIELD E

Short rotations with soil-building legume crops:												
13	2	10.82	3,813	17.85				Green manure, ³		34.4		
15		12.80	4,447	17.46				do. ³		40.8		
19		10.36	3,760	18.19				Hay ³		37.5		
33	3	15.32	5,506	17.80				Green manure, ³	199.7	40.7		
4-year rotations without soil-building legume crops:												
46-P	4	9.61	3,533	18.54				(³)	186.0			
46-O		9.66	3,445	18.01				(³)		30.8		
4-year rotations with soil-building legume crops:												
43	4	12.67	4,283	17.07				(³)	249.2	⁴ 41.2		
47		13.24	4,677	17.71				Green manure, ⁶	233.2	⁵ 41.1		
41		14.77	5,128	17.49				Pastured ³	279.3	⁵ 43.0		
Difference required for significance, odds 19:1:												
Field K		1.48	520	.82		0.88	0.725		36.93	8.36	6.56	
Field E		1.69	551	.64					43.65	6.45		

¹ Gross sugar calculated for each plot, not from average yield of roots and sucrose content shown.² First-year alfalfa represents the year the crop was seeded; in some years a small or no crop was harvested.³ No yield estimates made of sweetclover crops pastured or plowed under.⁴ After sugar beets.⁵ After potatoes.⁶ In this rotation oats seeded with sweetclover were grown in alternate years. The sweetclover was plowed under as green manure.



FIGURE 1.—*A*, As a result of continuous cropping, sugar beets yielded 6.1 tons per acre in 1940 on plot 2 at Scotts Bluff Field Station. This was the twenty-ninth consecutive crop. *B*, Sugar beets and potatoes alternated in rotation 20, and no applications of manure were made. The yield of sugar beets in 1940 was 6.6 tons. Additional growth of sugar beets is evident at the plot borders. (Photographed September 20, 1940.)

SHORT ROTATIONS WITHOUT LEGUME CROPS

In field K, as shown in table 2, were located rotations 20 and 22, 2 years in length; and rotations 30 and 32, 3 years in length. These four rotations represented intensive culture of the soil, and no crop residues or manures were applied. As cropping systems they are unprofitable, both from the standpoint of production of sugar beets and of other crops. These rotations were included as a basis for comparison with other rotations. The plots showed a marked uniformity in root yield,

sucrose percentage of roots, apparent purity, and gross sugar production. The average production for the last 12 years for these rotations was 7.79 tons of roots per acre, with an average sucrose percentage of 17.76, an apparent-purity coefficient of 92.3 percent, and 2,768 pounds of production of gross sugar per acre. Compared one with another, they do not even approach a significant difference in any of the items mentioned. The results obtained are comparable with those from plot 2 in showing that the high test for sucrose and the high apparent-purity coefficient have in no way compensated for low root yield and low production of gross sugar per acre.

Many factors are probably involved in the poor yields of sugar beets and other crops from the intensive rotations; the primary factor, however, seems to be decrease in soil fertility. This is indicated by the large number of very small beets that show no injury from disease. The harvests from these plots have included many very small beets—1 to 1½ inches in diameter. It has been difficult to find roots that weigh 2 pounds. On some of the plots from the better rotations many roots weighed 5 pounds or more. The top growth from the short rotations also was very small, and cessation of growth occurred early in the season.

Observations of these plots over a period of years have shown also that leaf spot, common damping-off diseases, root rot, and other diseases have increased. During the growing season many beet plants have died on these plots, and the stand at harvest has been about 55 percent. Growth of the roots remaining has not compensated for the loss of plants early in the season. Some careful studies are now under way regarding the prevalence of diseases of sugar beets on all these rotations. The diseases, however, are not considered the basic causes of low yields, and the observed increase in root-disease incidence seems directly related to soil fertility.

These four rotations have produced almost identical yields. Potatoes or oats alternating with sugar beets, or potatoes followed by oats, or corn followed by oats, do not apparently show any significant differential effects upon stand, size, quality, or disease incidence of the subsequent sugar-beet crop.

Rotation 46 was designated as a 4-year rotation. Sugar beets were grown following a crop of oats, however, and the second crop of sugar beets followed an intervening crop of potatoes. The rotation is therefore essentially similar to the 2-year rotations previously discussed. The yield from rotation 46 was somewhat higher than that from the 2-year rotations, but the differences should not be attributed to the cropping system. Rotations 20, 22, 30, and 32 were in field K and have been cropped under the present plan since 1912, whereas rotation 46 was in field E and was begun in 1926. It seems plausible to assign the differences to the shorter duration of rotation 46 and its field location.

All the intensive rotations with sugar beets have been unprofitable, as the yield of roots has been far below the average for the district. The average yield for the Scotts Bluff area on all farms is approximately 13 tons per acre. This includes beet crops from some of the poorer types of soil. Any satisfactory type of rotation on good land should produce 15 tons of roots per acre.

Consistently high sucrose percentages were found in all rotations

in which no legume crops were grown or manure applied (Nos. 20, 22, 30, 32, and 46). The 12-year averages for sucrose percentage for these rotations varied from 17.56 to 18.54. Between fields E and K there were no significant differences; within fields no indication of significant differences in sucrose percentages were found among rotations of this type. The apparent purity of the beets from the rotations is consistently high, and no significant differences are shown within the group of rotations.

A rotation that included sugar beets but did not utilize legume crops or manuring or both has, in a relatively short time, brought sugar-beet production to a very unprofitable level. A significant difference exists between the yields from the continuously cropped beet plots and those with short, intensive rotations. This might be taken as an indication that crop rotation increases the yield of sugar beets. The noteworthy finding is that in the short rotations the gain from inclusion of the other crops has not been sufficient to give profitable returns from sugar beets.

ROTATIONS WITH ALFALFA

The two legume crops used in the rotations were sweetclover and alfalfa. The alfalfa was grown for a hay crop and was planted in April, either with or without a nurse crop of small grain. Three crops of alfalfa hay were removed each year without any pasturing. Alfalfa remained in the rotations for a period of 2 or 3 years. In all rotations except No. 42 the alfalfa was allowed to make some spring growth before the land was plowed for potatoes. Spring plowing was done about June 1, when the alfalfa was approximately 1 foot high. Practically all the farms grow some alfalfa; it is the principal hay crop of the area.

Rotation 65 (not included in table 2) consisted of alfalfa 3 years (2 years for hay followed by 1 year for hog pasture), corn (hogged-off), oats, and sugar beets. In this rotation, begun in 1930, the first sugar-beet crop was grown in 1936, and data are now available for six crops for the period 1936-41. The average acre yield of roots obtained was 18.78 tons; the average sucrose percentage, 15.57; and the average yield per acre of gross sugar, 5,833 pounds. From 1912 to 1935 flax was grown in place of sugar beets in this rotation.

The 4-year rotations, including both alfalfa and sugar beets, were designated as 40 and 42. In each the alfalfa was planted without a nurse crop and cut for hay for 2 years. In rotation 40 the alfalfa was plowed about the first of June and potatoes planted. In rotation 42 the alfalfa was plowed early in spring and oats sown. Both rotations were begun in 1912. The yield for the last 12 years of rotation 40 was significantly higher than that of rotation 42 in acre yields of roots and of gross sugar.

The average sucrose percentage of the sugar beets in rotation 40 was lower than that obtained in rotation 42, but the difference of 0.5 percent is not significant. Rotation 40 produced, as an average, 1.75 tons more roots per acre and 468 pounds more gross sugar during the last 12 years than rotation 42. The difference in root weight is significant, and the difference in gross sugar production approaches significance.

The short rotation showed no indication that potatoes or oats vary significantly in their influence on the succeeding sugar-beet crop; therefore, the differences may be attributable, in part at least, to the method of handling the alfalfa rather than to the crops used in the rotations. The later date of spring plowing of the alfalfa for the potato crop that immediately preceded the sugar beets may be an important factor in the increased beet yield. Plowing alfalfa late in spring has become a common practice in this area.

On this station, there were no 5-year rotations including alfalfa and sugar beets. There were four 6-year rotations and one 7-year, however, in which alfalfa was grown. Rotations 60 and 62 were identical, except that rotation 60 included a crop of potatoes and rotation 62 corn instead of potatoes. The crop of sugar beets grown in rotation 62 in 1940 is shown in figure 2. In both rotations the



FIGURE 2.—Rotation 62 at Scotts Bluff Field Station, in which alfalfa was grown 3 years, followed by one crop each of corn, oats, and sugar beets. No manure was applied. The yield of sugar beets in 1940 was at the rate of 14.1 tons per acre. (Photographed September 20, 1940.)

sugar-beet crop was preceded by oats. There were no significant differences between yields of sugar beets from rotations 60 and 62. The yields were very similar to those of rotation 42.

Rotation 60 differed from rotation 40 in that the former continued the alfalfa crop one additional year and included one crop of oats. Acre yields of both roots and gross sugar were significantly lower for rotation 60 than for rotation 40. It has been recognized that alfalfa may reach a stage at which its soil-building effects are overshadowed by its drafts on soil nutrients. With rotations 60 and 40 the period may be approaching when such effects can be decisively shown.

Rotation 64 differed from rotation 60 in the placement of the oat crop in the rotation. In rotation 64 sugar beets followed potatoes and oats followed sugar beets. In rotation 60 the oats were between the potatoes and the sugar beets. Rotation 64 was the one yielding highest, with no manure applied. In acre yield of roots, rotation 64

was significantly higher than any of the intensive crop rotations or rotations 42, 60, 62, or first-crop sugar beets in rotation 71. The sucrose percentage of sugar beets from rotation 64 was not significantly different from that of rotation 60 or the first crop of beets in rotation 71, but was significantly lower than the sucrose percentages of all other rotations to which no manure was applied. In production of gross sugar, rotation 64 was significantly higher than any of the short rotations with intensive crops and significantly higher than rotations 42, 60, and the first crop of sugar beets in rotation 71. In the comparison of rotations 62 and 64, the difference in acre yield of gross sugar in favor of rotation 64, although large, did not reach significance.

The root yield of first-crop sugar beets in rotation 71 was slightly below the average for other rotations that included alfalfa, and the sucrose percentage and gross sugar production were lower than those from any other rotation that included alfalfa. These results are interpreted as evidence that manuring of second-crop sugar beets in rotation 71 had little carry-over effect on first-crop sugar beets of the next cycle.

The average acre yield of sugar beets for the six rotations that included alfalfa was approximately 14 tons. The sucrose-percentage average was approximately 16 percent. The average gross sugar per acre was approximately 4,500 pounds. Compared with short, intensive rotations, an increase of 6.25 tons of sugar-beet roots per acre has been obtained, and more than 1,700 pounds of gross sugar. These significant gains were accompanied by a reduction in sucrose percentage of 1.75, though the quality of the sugar beets was entirely acceptable for processing.

The inclusion of alfalfa in the rotation increases sugar-beet yields materially and also influences favorably the returns from other crops in the various rotations. Increased benefits are derived from plowing under alfalfa that has some top growth, thus in a measure utilizing it as a green-manure crop.

ROTATIONS INCLUDING SWEETCLOVER

Rotation 45 in field K had two crops of sugar beets followed by a crop of oats that served also as a nurse crop for sweetclover. The sweetclover was pastured after the oats were removed and again in the following year. No applications of barnyard manure were made. Pasturing sweetclover the second year eliminated sweetclover as a weed in the beet crop. First-crop sugar beets following sweetclover gave average yields of roots and gross sugar significantly better than those of a second crop of beets in this rotation. Sucrose percentages of the first-crop sugar beets were significantly lower than those from the second crop.

Rotation 45 proved to be a very profitable one. The first crop of sugar beets was significantly higher in yield than those from rotations 42, 60, 62, and first-crop sugar beets of rotation 71. The same relation holds for gross sugar production. The average sucrose percentage of sugar beets given in rotation 45 was not significantly different from those determined for rotations 40, 42, 60, and 62.

As a factor in the results from rotation 45, pasturing by sheep must be recognized. The sheep used for pasturing the sweetclover were

confined to the small pastured area during the entire pasturing period, and no housing was provided. Probably no rotation of the entire series has aroused more interest from practical sugar-beet growers than the pasturing feature in the management of this rotation and its resultant direct benefits.

The rotations in field E, 2, 3, or 4 years in length, were begun in 1926 for a study of the benefits from sweetclover in the crop rotations in the North Platte Valley. Sweetclover was not grown extensively in the area at that time. Several practices not commonly now used in the area were included in the rotations in that field. Other practices that were used in the field have now been widely adopted in the Scotts Bluff area. Sugar beets were grown in eight of the nine rotations and white biennial sweetclover in all; no manure was used in any of them.

Rotation 46, in which two crops of beets were grown with intervening crops of potatoes or oats, respectively, was intensive and afforded a basis for evaluation of the rotations in field E that did include sweetclover. The 10-year-average acre yield was 9.64 tons. No significant differences were found between first- and second-crop sugar beets. Rotations 13, 15, and 19 of field E were 2-year rotations in which the sweetclover was planted with oats as a nurse crop, the oats being harvested for grain. Three variations in the management of the sweetclover crop were employed in these rotations. The sweetclover in rotation 19 was cut for hay, in rotation 13 it was pastured with sheep, and in rotation 15 it was left to grow undisturbed as a green-manure crop. In all three rotations the plowing was done about November 1, when the plants were in dormant condition.

The sugar-beet yields from rotation 15 exceed the other two significantly, both in root yields and in production of gross sugar. The recession of sucrose percentage was small and was a minor factor in the results. Rotations 13 and 19 did not differ significantly from rotation 46 in root yields and gross sugar production, indicating that the utilization made of the sweetclover by this management was essentially intensive cropping, as little or no benefit to the sugar-beet crop was derived from pasturing the sweetclover or cutting it for hay in its first growing season. On the other hand, in rotation 15, in which considerable growth of sweetclover was plowed under in the fall as green manure, definite benefit accrues to the succeeding sugar-beet crop.

The observations made on these rotations do not warrant the conclusion that no improvement in soil fertility took place in the short period of growth of sweetclover. There is clear evidence that it is not advantageous to follow sweetclover immediately with sugar beets, because of the persistence of sweetclover as a weed. The large number of living sweetclover plants in the sugar-beet crop presents a rather serious problem of weed control in the sugar-beet plots each season.

In direct contrast with rotations 13, 15, and 19, in which sweetclover proved to be a troublesome weed in the sugar-beet plantings, are the results from rotations 33 and 41 of field E. Rotation 33 was a 3-year rotation in which sweetclover was planted with oats as a nurse crop, the sweetclover being allowed to grow until about June 10 of the following year, when it was plowed under in preparation for the

potato crop. The sweetclover commonly reached a height of 2 to 4 feet when plowed under. By this method of handling, the sweetclover has been a minor factor as a weed in the potato crop and is not found as a weed in the sugar-beet crop that follows potatoes in the third year.

Rotation 41 was a 4-year rotation in which the sweetclover planted with oats as a nurse crop was pastured with sheep after the oat harvest, and again in the second year. The sweetclover was fall-plowed in preparation for potatoes, the sugar-beet crop being grown in the fourth year. With this rotation also, sweetclover has been eliminated as a weed in the sugar-beet crop and is of minor importance in the potato crop.

Both rotations 33 and 41 are outstanding among rotations at the Scotts Bluff Field Station. Rotation 33 is ranked the highest with respect to the sugar-beet crop of any of the sweetclover rotations in field E, but in comparison with rotation 41 the differences are not significant, the advantage of rotation 33 being perhaps attributable to field locations of the two rotations.

As a 10-year average, sugar beets in rotation 33 have given an acre yield of roots of 15.32 tons and of gross sugar, 5,506 pounds; sucrose percentage averaged 17.80. Rotation 41 averaged 14.77 tons of roots per acre, testing 17.49 percent and yielding 5,128 pounds of gross sugar. In short, the two rotations employing sweetclover in an efficient way obtain maximum green-manuring effects and avoid complications of sweetclover as a weed. They averaged through the years about a 15-ton sugar-beet crop of exceptionally high average sucrose and a consistent gross sugar production well over 5,000 pounds per acre.

Rotations 33 and 41 have, along with rotation 45, previously discussed, attracted favorable attention. Rotation 45 provided two sugar-beet crops in a 4-year cycle, whereas rotations 33 and 41 provided for potatoes and sugar beets as the intensive crops. Probably the best evidence of the significance of the findings on methods of utilizing sweetclover is the wide adoption of these cropping methods in irrigated districts of Nebraska and adjoining States.

Rotations 43 and 47 included oats seeded with sweetclover. The following year, the land was plowed late in spring for potatoes. In the third year, oats were again sown as a nurse crop for sweetclover and the sweetclover was fall-plowed for sugar beets. In rotation 43, the sweetclover was pastured with sheep, and in rotation 47 it was left undisturbed. The manner in which the sweetclover was handled, that is, pastured or unpastured, was the only variation in these two rotations. Rotation 47 may prove slightly better than rotation 43, but as yet there are no significant differences in the results from the sugar-beet or other crops.

Rotations 43 and 47 are comparable with rotations 13, 15, and 19 in that fall plowing of sweetclover is practiced in preparation for sugar beets. In all five rotations sweetclover has persisted as a weed. It is to be noted that rotations 43 and 47 fall definitely behind rotations 33 and 41 in the average productiveness of the sugar-beet crop, enough so to bring into question the relative efficiency of utilization of the sweetclover crop. The definite value from the late-summer and fall growth of the green-manuring crop, however, is shown.

VALUE OF MANURE WITH CROP ROTATION

The addition of manure to any crop rotation in the 12-ton rate used has in all instances brought about significant increases in tonnage and gross sugar and relatively slight decreases in sucrose percentage. No great depression in sucrose percentage was to be expected, as none of the rotations here studied received large quantities of manure. In other experiments at the station it has been found that the application of 12 tons of manure per acre per year for a period of 5 years to sugar-beet crops continuously grown does not greatly depress the sucrose content. The use of more than 12 tons of manure per acre each year does not increase acre returns, as measured by indicated available sugar produced above the returns obtained from using 12 tons of manure per acre. This failure to obtain benefits from the increased quota of manure is largely caused by the depression of the sucrose content of the beets.



FIGURE 3.—Rotation 23 at Scotts Bluff Field Station, in which the sugar beet and oat crops alternated. Twelve tons of manure per acre were applied to the sugar beets. The yield in 1940 was at the rate of 19.2 tons per acre. (Photographed September 20, 1940.)

In rotations 21 and 23, the 12 tons of manure were applied in alternate years. The sugar-beet crop in rotation 23 in 1940 is shown in figure 3. In rotation 31, the manure was applied each third year; in rotation 61, once in 6 years. In rotation 71, the manure was applied to the second-crop sugar beets once in 7 years. In all instances, the beet crop received the benefit of direct application of the manure, except in rotation 21, in which the manure was applied before planting the potato crop. Four direct comparisons with similar rotations to which no manure was applied are furnished by the rotations reported.

A fifth comparison is afforded by the data in table 2, namely, the comparison of the two beet crops in rotation 71. In this rotation, second-crop sugar beets receive the direct benefit of manure, first-crop sugar beets being grown on the same plot 6 years later. Study of the data indicates that the first crop of sugar beets in rotation 71 obtained little benefit from any residual effect of the manure applied 7 years previous to the other beet crop. Of course, residual effects from manure cannot be definitely determined, but the indications are that they tend to disappear after a number of years. Rotation 60 did not receive manure. During the 12-year period the average acre yield of sugar beets from this rotation was 13.45 tons. The average yield from rotation 71-1 was 13.57 tons. For this reason inclusion of rotations 71-1 and 71-2 in the comparisons between the crops receiving manure and those not receiving manure seems justified.

The results of these five comparisons show that manure applications provide an average gain in acre yield of roots of nearly 7 tons, and an average gain in acre yield of gross sugar of 2,313 pounds. The drop in sucrose percentage is so slight (numerical decrease of 0.14) as to be negligible. The highest average sucrose percentage obtained from any plot receiving manure was from rotation 31. Likewise, this rotation produced more gross sugar per acre than any other.

As stated, the three short intensive rotations without manure have given extremely low yields of sugar beets; hence, comparisons of these rotations with and without manure applications are to be expected to reveal striking differences. The increase in acre yield of roots from the use of manure is almost 10 tons, and the gross sugar produced is more than twice that produced from similar rotations to which manure was not applied.

In the rotations in which alfalfa was included in the cropping system, there was a gain in root yield of approximately 6 tons per acre that may properly be credited to the effects of alfalfa in the rotation. The use of manure as direct applications to the sugar-beet crop in rotations 61 and 71-2 added approximately another 4 tons per acre to root yields. The data, therefore, very clearly indicate beneficial increases in sugar beet productivity, both from the use of alfalfa and from manure. The yields of potatoes, oats, and other crops in these rotations were also increased by the use of manure and of alfalfa (table 2). Photographs taken in 1940 (fig. 4, *A* and *B*) show representative crops of sugar beets as obtained in these two rotations. The heavy growth is in decided contrast to that shown in figure 1, in which the sugar beets were grown without manure and without inclusion of a legume crop in the rotation. These views may also be compared with figure 2, which shows a 6-year rotation that included 3 years of alfalfa but no application of manure.

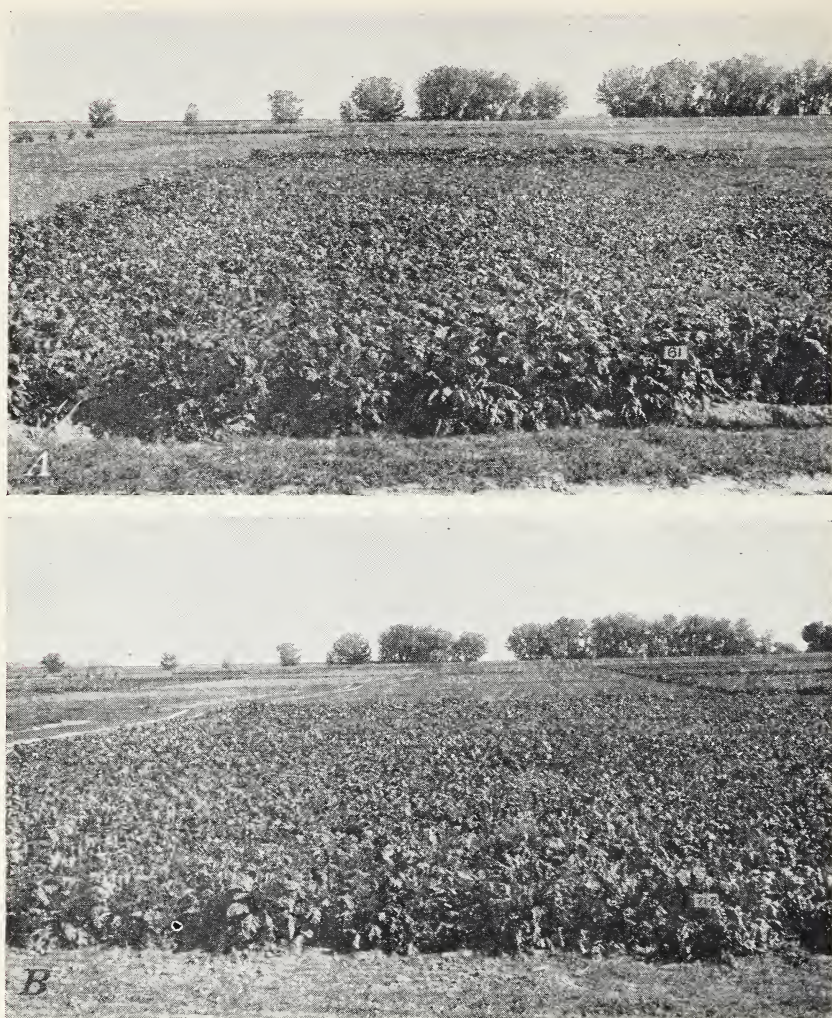


FIGURE 4.—*A*, Rotation 61, in which alfalfa was grown 3 years, followed by potatoes, oats, and sugar beets, one crop of each. Twelve tons of manure per acre were applied to the sugar-beet crop. The yield of sugar beets in 1940 was at the rate of 14.8 tons per acre. *B*, Rotation 71-2, in which the cropping program was alfalfa (3 years), potatoes, sugar beets, sugar beets (manured), and oats. Sugar beets (manured) yielded at the rate of 15.8 tons per acre in 1940. (Photographed at Scotts Bluff Field Station, September 20, 1940.)

SUMMARY AND CONCLUSIONS

Crop rotations for 1930 to 1941 at the Scotts Bluff Field Station, Mitchell, Nebr., developed important facts on proper rotation practices and on the value of manure for growing sugar beets. Some of the rotations definitely show that omission of legumes from a rotation and omission of manurial applications lead to poor yields. Associated with low yields are poorer stands.

The sucrose percentage of sugar beets was slightly depressed by the inclusion of legume crops in the rotation, but in no case did it lower quality to such an extent as to make the roots unacceptable for processing. Furthermore, any effects on sucrose percentage were more than counterbalanced by gains in root weight, as evidenced by the high gross sugar returns. The same is true regarding the slight depressions of sucrose percentage with manure applications at the rate of 12 tons per acre.

Continuous cropping to sugar beets as done in plot 2 produced an average acre yield of 5.65 tons of roots, testing on the average 18.13 percent of sucrose. The acre yield of gross sugar, as calculated, was only 2,044 pounds. These data represent the highest sucrose percentage of beets grown in field K and the lowest tonnage of roots and the lowest production of gross sugar in any series of the rotation trials. The type of cropping is a good example of what not to do in sugar-beet culture.

The four short, intensive, rotations produced an average of 7.79 tons of beets per acre and 2,768 pounds of gross sugar, with an average sucrose percentage of 17.76. A slight increase in tonnage of roots and of gross sugar over that obtained by continuous cropping of beets was accompanied by a slight decrease in sucrose percentage. Potatoes, oats, and corn showed no measurable differential effects upon the succeeding sugar-beet crop. Alternation of intensive crops obviously is a poor type of cropping system.

The inclusion of alfalfa for 2 years in the two 4-year rotations in field K was beneficial to the sugar-beet crop. Plowing under alfalfa in late spring as a green-manure crop gave significantly favorable results on root yield of sugar beets as contrasted with late fall plowing. In rotation 45, in which sweetclover was pastured with sheep, the yield was slightly better than that obtained when a green crop of alfalfa was plowed under. Choice between these rotations would depend upon the returns from the alfalfa hay and the sweetclover pasture. The 4-year rotations that included alfalfa or sweetclover showed a slight decrease in sucrose percentage when compared with short, intensive rotations. The inclusion of an alfalfa or a sweetclover crop in sugar-beet rotations produces such distinct gains in root yield and in corresponding yields of gross sugar that the slight drop in sucrose percentage may be wholly disregarded.

The rotations in which alfalfa was grown for 3 years produced sugar beets having slightly lower sucrose content than those produced by the 4-year rotations in which alfalfa was grown for 2 years. These 6-year rotations are very satisfactory and are favorable to a proper distribution of labor and irrigation water on the typical farm in this area. This type of rotation with no manure applied is one that can be used in a farming system in which the alfalfa hay is sold.

The addition of manure to short rotations more than doubled the acre yield of gross sugar and increased that of roots by more than 10 tons. On the average farm, however, feeding the crops and crop residues does not produce sufficient manure to maintain an intensive cropping system and to permit manuring the sugar beets each time. The data do, however, give valuable evidence as to how to repair promptly soil depletion occasioned by intensive cropping.

The 6- and 7-year rotations which included alfalfa and in which

manure was applied to the sugar-beet crop are of a type that can be practiced on most farms in this area. By proper methods of handling, these rotations permit a greater quantity of manure to be obtained and applied, so that soil fertility is increased rather than decreased. These rotations produced sugar beets of approximately 15.9 percent sucrose and approximately 17 tons of beets per acre, demonstrating their desirability.

The rotations in field E contrasted short rotations that included sweetclover with somewhat longer rotations with and without this soil-building legume crop. In three of the 2-year rotations in which the oat crop was used as a nurse crop for sweetclover immediately preceding sugar beets, mediocre returns were obtained from the beet crop when the sweetclover was fall-plowed. The yields of roots and sugar were better than those obtained by a rotation in which no sweetclover was grown but fell short of what is possible by more efficient management of the sweetclover. A rotation in this 2-year series in which sweetclover was spring-plowed as green manure for a potato crop provided an increase of approximately 5 tons of beets per acre, in comparison with fall plowing of sweetclover. Excellent returns also were obtained when the sweetclover was pastured during two seasons prior to growing the beets.

The results obtained over the 12-year period have confirmed in all important particulars the preliminary conclusions drawn from the 6-year cycle first summarized. In general, unfavorable rotations reported on the basis of 6 years have continued unfavorable, with definite trends toward still greater reduction in sugar-beet yields. The favorable rotations that utilize alfalfa and sweetclover and those in which manuring is used to supplement the legumes continue favorable, often showing a definite uptrend in sugar-beet yields.

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